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STATE-OF-THE-ART STUDY ON THE PULSED-LIGHT PHENOMENON

Report No. BAT-171-6

Prepared Under Contract SD-171

December 4, 1964

By

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February 10, 1965

Advanced Research Projects Agency
Office of the Secretary of Defense
Washington, D. C. 20301

Attn: Project AGILE

Gentlemen:

Enclosed are ten copies of our report, "State-of-the-Art Study on the Pulsed-Light Phenomenon" (Report No. BAT-171-6), and ten copies of the Confidential addendum to this report, "Summary of 'The Development of Weapons for Psychological Warfare' - A Study Conducted by the Falcon Research and Development Co."(U) (Addendum Report No. BAT-171-6-1). This report and its addendum comprise the first in a series of five reports on incapacitating agents.

We will welcome any comments or suggestions in regard to this study.

Sincerely,

John W. Murdock

John W. Murdock
Project Director
RACIC

JWM:krs

Enclosures (20)

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INTRODUCTION AND OBJECTIVE

This the first of five reports on the state of the art in the development of certain incapacitating agents. The objective of this study was to summarize information, and to identify points on which more information is needed, regarding the pulsed-light phenomenon i.e., the effects of flicker at rates corresponding to the alpha rhythm of the brain.

During this six-week study approximately 300 documents were reviewed. These pertained to the pulsed-light phenomenon, and to related aspects of electroencephalography, epilepsy, and hypnosis and suggestion. The relevant information was extracted, interpreted, and summarized to provide this report. Criteria for the inclusion of material in this study were as follows:

(1) Incapacitation, rather than mere annoyance, is the goal.

(2) The stimulus of interest is flickering light; other stimuli such as sound, suggestion, drugs, etc., are of interest only as they may enhance or facilitate the disorganizing effects of pulsed light.

(3) Feasibility is a primary issue; therefore, data on the probable percentage of population susceptible, the probable degree and duration of ill effects, and the equipment requirements for producing the phenomenon in the field were given first priority.

(4) The quality of the available reports and data was considered in interpreting the findings of the literature survey. Where the data were sketchy or the experimental procedures weak, the resulting weakness of the conclusions drawn has been indicated.

A brief summary of the major findings is provided in the next section. Following that, the body of the report is introduced by a general description of the problem area. The next section, an extensive technical review of the pulsed-light phenomenon, reports the bulk of the technical findings in some detail. The remaining sections deal with research trends, methods for combat use, conclusions, and references. The appendixes list the publications that were searched for references, and acknowledgment of persons who assist in the survey.

SUMMARY

In general, the findings indicate a low probability that pulsed light can be used as an effective weapon. The chief drawbacks from its feasibility are these:

(1) Estimates of the per cent of population which can be significantly affected range from 1 to 5 per cent, with most investigators making the estimate 1 per cent or less.

(2) The evidence suggests that the per cent effectiveness might be decreased if members of the target population were intent on some task.

(3) Light sources for use in the field would be cumbersome, easy for the enemy to avoid, and easy for snipers to hit.

(4) In some cultures, phenomena such as seizures and hallucinations have positive rather than negative connotations. Possibly some groups would interpret these phenomena as good omens.

The background information leading to the interest in pulsed light as a potential weapon can be summarized very briefly. Recordings (electro-encephalograms or EEG's) of electrical activity from the human brain were made in 1924 by Berger, who identified and named the predominant wave (alpha wave) of the electrical activity. In the 1940's, it was found that alpha rhythm can be controlled by photic driving, i.e., by having the subject watch a flashing light. Later it was discovered that pulsing at certain frequencies can induce epileptic attacks in some epileptic patients.

Self-induced epileptic seizures were reported even among the ancient Greeks. Clinical cases down through the years have revealed various techniques for self-induced attacks based on interrupted light. A number of accidental cases have also been reported, particularly in modern times.

Photic driving has been used frequently as a stimulus in the laboratory study of brain function. Regrettably, the vast majority of this work has not been concerned with behavioral manifestations, but solely with EEG records. Thus, it has been demonstrated that one can induce, in normal subjects, alterations in the normal EEG pattern. But the real question is whether it necessarily follows that such alterations are accompanied by behavioral disturbances of sufficient severity to result in dysfunction.

The answer to the critical question is negative, but it is qualified by many considerations concerning the composition of the subject population, the specific method of photic driving, and the preconceptions of the investigators.

Moreover, some confusion exists about the possibility of two basic kinds of detrimental effects from flicker. The original, and still primary focus has been on the photically induced phenomena of epileptiform EEG patterns and the frequency with which they are accompanied by epileptic seizures, muscle jerks and twitches, trance-like states, and drowsiness. A less serious, but still noteworthy, class of effects lies in the so-called distracting effects, ranging from annoyance through distraction to dizziness, headache, and nausea. Although some of the literature treats these as separate phenomena, quite possibly they simply reflect the two extremes of a common continuum.

In the survey of the literature, it has been found that light-to-dark ratios from 1:1 to 10^4:1 have been used. Behavioral manifestations, when they do occur, can be found at both of these extremes and, within epileptics, even as the result of a single flash. The same is true in regard to illumination level. EEG activation (paroxysmal discharges) has been found in some at levels of 100 to 200 foot-candles and absent in others at levels up to one million lux. The total durations studied have ranged from as short as 30 seconds to as long as 2-1/2 hours, with negative results.

The color effect of the light has also been studied, but as in the case of other parameters, no positive conclusion can be made.

Frequencies, generally within the alpha range, have also been varied to as low as 1 per second and as high as 100 per second with variable results. Mild drowsiness can be attained, for example, at 1 cycle per second or at frequencies of 10 to 15 per second (i.e., within the alpha range). It should be emphasized that the production of severe incapacitating effects, e.g., grand mal seizure, rarely occurs as the result of employing any of these techniques, except within a small portion of the epileptic population.

DESCRIPTION OF PROBLEM AREA

The question that is basic to this survey is whether pulsed light is a feasible military tool for producing personnel incapacitation. Generally, it has been inferred that because pulsed light apparently can alter the alpha rhythm of the human brain, it can also alter behavior and hence military performance. Confidence in these inferences is based in part on the known occurrence of photically induced epileptic attacks.

In addition to motor seizures, other forms of disturbance have been reported. These disturbances are far less dramatic than muscle spasms; they include drowsiness, headache, and nausea. Nonetheless, they might hinder effective military performance.

Figure 1 summarizes the hypothesized situation in graphic form. At the left side of the figure, pulsed light is shown as an input to the human being. Next, to the right, is the physiological link between the input and the resultant behavior. Then come the possible behavioral effects which might be displayed by the cognitive system and the motor system, i.e., the human musculative. Last, at the right of the figure, is the combat performance as influenced by these effects.

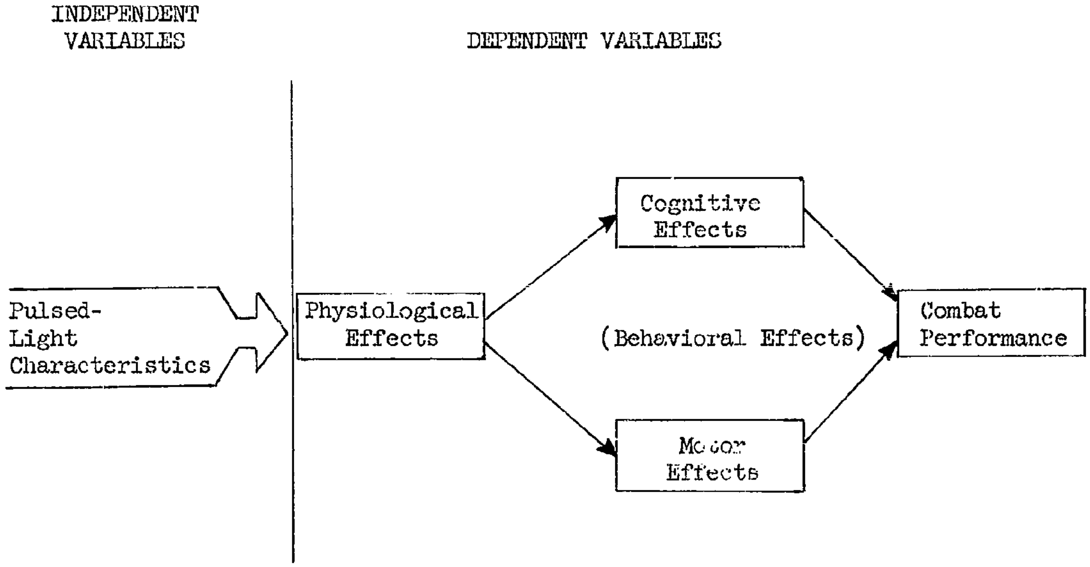

FIGURE 1. PRESUMED SEQUENCE OF EFFECTS OF PULSED-LIGHT INPUTS TO HUMAN SUBJECTS

It is to be noted in Figure 1 that there is one set of independent variables (characteristics of pulsed light), and four sets of dependent variables which can be measured. Thus, as pulsed-light characteristics, e.g., intensity, pulse rate, and wavelength, are varied, one can measure the effects in any of the four groups of independent variables, for example, incidence of epileptiform alpha waves (physiological effects), decrease in ability to perform calculations (cognitive effects), hand steadiness (motor effects), or decrease in per cent of troops firing on target (combat performance).

The present study is ultimately interested only in two sets of variables; namely, the effects of (1) pulsed light on (2) combat performance.

There is no intrinsic interest, for the military, in the three remaining sets of dependent variables. For present purposes, these variables are interesting only insofar as they may be predictors of combat performance. And yet the correlation of the physiological variables with the cognitive and motor variables, and of the latter with combat performance, is uncertain.

In spite of all this, most of the studies on which this review is based deal with physiological effects, viz., abnormalities of the brain's electrical activity as reflected in the alpha wave recorded on the electroencephalograph. The reason is simply that most research using pulsed light has been basic research on brain functioning. Therefore, most available literature on pulsed-light effects deals with EEG records.

Behavioral data have been included to the extent to which such data are available. Virtually no combat performance data are available, even from experiments performed under simulated conditions.

TECHNICAL REVIEW

General Background

EEG - Historical

Laboratory experiments have universally shown that drowsiness, sleep, and epileptic seizures are accompanied by characteristic patterns of electrical brain activity that can be recorded by the electroencephalograph. As a result most research on the effects of photic stimulation has utilized the EEG as a laboratory tool to gauge the state of the subject. To better understand this reported research, some familiarity with the EEG and related terminology is desirable. Toward this end a brief review of applicable subject matter is reported below.

As with almost all fundamental discoveries in physiology, experiments on animals provided the first evidence of the electrical nature of cortical activity. The English physiologist Richard Caton in 1874 discovered that electrical pulsations were produced in the brains of rabbits. In 1924 a German psychiatrist, Hans Berger, succeeded in making the first recordings of electrical activity in the human brain with an instrument he called an electroencephalograph (now popularly referred to as an EEG). This was followed in 1942 by W. Grey Walter's invention of the electrical analyzer, which separates the electrical pulsations into their frequency components. More recently the electronic computer has emerged as a valuable instrument in signal processing, particularly for extracting meaningful signals from background noise levels, which sometimes completely mask the information content of interest in EEG recordings.

EEG Patterns

EEG records in normal human beings usually exhibit a mixture of rhythmic wave patterns, with frequencies varying from 1 to 60 per second and amplitudes of 20 to 60 millionths of a volt as measured between electrodes placed on the unshaved scalp. Four types of electrical activity are distinguished; these are known as the alpha, beta, delta, and theta waves.

Alpha waves are customarily found in the normal human adult while sitting or lying undisturbed in a relaxed state. Alpha waves fall in the frequency range from 8 to 13 cycles per second. When the subject's attention is concentrated, alpha activity disappears or is blocked, and is replaced by low-voltage, rapid, irregular waves. This lower voltage, fast activity in the range above 16 cycles per second is called the beta wave. Delta rhythms are slow waves with frequencies of 0.5 to 3 cycles per second and of appreciably larger amplitude than the alpha wave; they appear in the normal subject when he is asleep. These waves are mixed with short spindles of waves at 14 cycles per second, known as "sleep spindles". Rhythmic slow waves, at frequencies between 4 and 7 per second, have been called "theta waves" and appear in normal young children as the counterpart of the alpha rhythm in adults.

In addition to these spontaneous brain rhythms, there are transient electrical potentials that occur in response to the arrival of sensory nerve impulses. Such impulses can be evoked by stimulation of the subject through his sensory mechanism.

Use of EEG

Although most of the activities of the brain cannot be related closely to the EEG, since it records only a small sample of the activity from the brain's surface, the EEG record has proven useful for diagnosis of gross brain damage and seizure activity. EEG records show that epileptic seizures are the outward manifestations of a profound disturbance in the electrical activity of the brain. In contrast to the predominating 8 to 12-cycle-per-second and 20 to 60 μvolt wave activity of the normal adult, an EEG recorded immediately before and during an epileptic seizure is characterized by bursts of high-amplitude (above 100 μ volts) activity consisting of either spikelike waves of high frequency (above 15 cycles per second), broad flat-topped slow waves (less than 6 cycles per second), or an approximate 3 per second alternation between a spike and slow wave.

Induced Seizure

The incidence of a significant number of photogenically induced epileptic seizures has stimulated intense interest in photic stimulation since the mid-1940's. That seizure activity can be elicited by photic stimulation has been unquestionably demonstrated by a number of clinical histories of light-sensitive epileptic patients intentionally exposing themselves to such stimuli as rapid blinking, hand movement with fingers spread, gazing through fine patterns, nodding the head rapidly, and the like. These actions are followed by convulsive attacks and sometimes unconsciousness.

The incidence of self-induced epilepsy is considerably more rare than the normal photosensitive epileptic who can be induced into a seizure by photic stimulation with a flashing light in the laboratory. As a result, the use of photic stimulation as an EEG activating technique to aid in the diagnosis of epilepsy has become accepted laboratory practice. In the conduct of this laboratory procedure, the incidence of epileptic-like discharges in the EEG records of apparently normal subjects has also become well established. These evoked discharges suggested the possibility that photic stimulation might be used as a weapon for inducing epileptiform discharges, and hence seizures in a significant portion of a population.

EEG and Behavior

Most of the studies on response to photic driving, not being concerned with the production of incapacitating effects, have reported primarily or exclusively on EEG responses. Apparently some investigators have assumed that an abnormal EEG pattern always implies behavior disorganization and vice versa. But in fact, an invariant relation between EEG patterns and behavior patterns simply has not been demonstrated. Some persons who respond to photic pulsing with abnormal EEG response will also show abnormal behavior; others will not. Some persons who exhibit normal EEG patterns may show behavioral impairment.

The relationship between EEG alpha frequency and personality variables has been extensively investigated in the past and is still the subject of intensive inquiry. In a review Ellingson(12)* concluded that no definite relationship between EEG characteristics and personality variables had been substantiated up until that time (1956). Other authors, including Karp, Pollack, and Fink(20), while agreeing that there is a lack of relationship between EEG variables and psychological measures, contend that there is a relationship between changes occurring in the resting EEG pattern and behavioral measures. Nothing was said by the latter authors about the relationship between behavioral measures and such EEG changes as might be induced by artificial means such as photic driving. These authors suggested that a fruitful area of inquiry might be an investigation of artificially induced changes such as those produced by drugs.

*Superscript numbers in parentheses refer to items listed in the references.

Davidoff and Johnson(10) directed a study toward the question of whether paroxysmal EEG activity generally is associated with dysfunction. They report a series of experiments in which subjects performed cognitive-motor tasks in the presence of paroxysmal EEG activity. In some cases the activity was spontaneous and in other cases it was induced by photic stimulation. All 36 subjects were patients whose diagnosis was ideopathic seizure disorder or unexplained episodic loss of consciousness. The general result was that the duration of each paroxysmal discharge, and its classification as clinical (diagnostic for epilepsy) or sub-clinical, were the principal factors in determining whether the given discharge was likely to be associated with a break in task performance. A discharge of long duration, whether of clinical form or not, was likely to be associated with dysfunction. A discharge of clinical type was much more likely to be associated with temporary loss of function on the test tasks. It is also significant that paroxysmal bursts longer than a few seconds were likely to be associated with a break in cognitive-motor performance.

Johnson(16) reported on Watson's* finding that approximately 6 per cent of candidates for Army helicopter pilot training demonstrated abnormal EEG discharges during photic stimulation. Watson recommended that all helicopter pilots be examined for sensitivity to flickering lights.

*Watson's report is an important work which was not reviewed in the present study. Battelle was unable to locate a copy, referenced by Johnson as follows: Watson, C. W., "Detection of Light Evoked Cerebral Electrical Abnormalities Among Helicopter Pilot Trainees", Progress Report to R&D Dir., Office of Surgeon Gen., Dept. of Army, Contract DA-49007 MD-734, September, 1959.

Johnson, Davidoff, and Mann[18] reviewed previous research relating paroxysmal EEG activity to performance. They found conflicting results. Quoting them:

> "Using a variety of tasks and subject types, Bates (1953), Kooi and Hovey (1957), and Yeager and Cucrrant (1957) have reported impairment in cognitive and/or motor performance during abnormal EEG activity. Schwab (1939), Jung (1954), Gastaut (1954), and Shimazo, Hiral, Fukuda, and Yamamasu (1953) report varying degrees of impairment in petit mal patients. On the other hand, Milstein and Stevens (1961), Johnson, Ulett, Sines, and Stern (1960), and Prechtl, Boek, and Schut (1961) have reported no impairment in performance during abnormal electrical bursts. Mirsky, Phimac, Ajmone-Marsan, Roswald, and Stevens (1960) reported that patients with centrencephalic seizures did significantly poorer on a test of sustained vigilance than did patients with focal temporal lobe seizures. In the latter study, however, simultaneous EEG tracings were not obtained and thus one can only speculate as to whether or not the impairment in functioning occurred during a paroxysmal discharge."

Kooi, Eckman, and Thomas[21] found some degree of photic driving in all 90 members of their control (normal) group. Lesser degrees of photic driving were shown by a group of patients (52 classed as "organic group without ocular involvement"; 20 as "organic group with ocular involvement"; and 8 as "organic group with homonomous hemianopsia"). The stimulus frequency varied between 1 and 30 per second, with a 20-second "on" period and 20 seconds between presentations. Twenty different fixed frequencies were used. Variable stimulation was also applied starting at 3 per second, increasing to 20 per second, decreasing to 10 per second, and then rapidly rotating between 10 and 15 per second. A Grass PS-1 stimulator, giving a blue-white light of 10-microsecond-duration flash with peak candlepower about 375,000, was placed 15 centimeters from the eyes. Tests were conducted in a dimly lit room and eyes were closed throughout the procedure. Four of the organic group demonstrated photomyoclonic responses, but none was seen in the control group. No other behavioral manifestations were indicated.

Ulett and Johnson(33), commenting on the above study, concluded that "photic driving is a universal phenomenon", but that "...the significance of a single EEG record, even an activated one, is certainly open to considerable question. In one individual previously reported, changes in blood sugar and the amount of sleep seemed to combine to increase the cortical sensitivity to flickering light."

In the same paper(33), these authors reported a study of 182 healthy young male adults and 53 psychiatric patients. Marked or extreme photic activation occurred in 8.8 per cent of the healthy group and 24.5 per cent of the psychiatric group, but no behavioral effects were found. Stimulus parameters were: 1:1 light-dark ratio; 3 to 33 flashes per second; source, a projector bulb focused on a screen mounted 6 to 12 inches from the subject with an illumination of approximately 100 to 200 foot-candles, thus filling the whole visual field with light.

Case Studies

Two case studies are included here. Both are cases of photically induced epilepsy, one in an epileptic patient and the other in a healthy individual. These studies are presented not because of any conclusions which can be drawn from them, but rather because they are clear demonstrations.

Detailed Study With an Epileptic Patient

While it is recognized that the principal question is whether some proportion of a population of normal, healthy human subjects can be disabled by photic flicker, nevertheless it is fruitful to consider such studies as are available on photic-flicker activation of known epileptics. In these cases, the phenomenon of photically induced seizure can sometimes be elicited very readily and thereby studied under well-defined laboratory conditions. Marshall, Walker, and Livingston[24] provide an excellent example of such a study from which considerable value was gained because of the cooperativeness of the subject and other circumstances. From this case it was learned that at relatively high light intensity, the patient would react to any frequency from 2 to 20 cycles per second with strong activation patterns that would proceed to generalized seizure if continued long enough. However, as brightness was decreased, it was apparent that there were two critical frequencies which would suffice to bring about activation even at low light intensity. These frequencies were 8 and 16 cycles per second.

By the use of filters, the effect of different wavelengths was examined. Red light was approximately 10 times as effective as white light at a given frequency. It was particularly interesting that, when the patient was subjected to threshold-level photic stimulation and simultaneously exposed to a sonic click introduced about 1 millisecond after the light flash, there resulted only moderate dysrhythmia which did not proceed to the seizure pattern. Increasing light intensity by a factor of 4 was found to overcome the inhibiting effect of the sound. Other means of peripheral stimulation failed to demonstrate this inhibiting effect. Amphetamine and phenobarbitol injected intravenously failed to show any shift of threshold.

Case Study With a Non-Epileptic Subject

Descriptions of genuine photo convulsion are rare in the literature. Such descriptions generally refer to events occurring during photic stimulation of epileptic subjects. Special interest is therefore found in a recent paper by Davidoff and Johnson[11] describing photo-convulsive responses in a non-epileptic subject. A 19-year-old man, with negative neurological examinations and resting electroencephalogram, reacted to flicker within the alpha frequency range with diverse occurrences such as hallucinations, unusual electroencephalographic pattern, autonomic nervous-system changes, and a grand mal seizure. The authors concluded that the induced dysfunction of the brain involved both occipital lobe structures and subcortical areas as well. The significance of this paper lies in the demonstration of photo convulsion in a young healthy and normal Caucasian.

Two Major Reviews

Special attention should be given to two references. First is the study by Obitz and McCord[28] because it reviews the literature, and because it is very recent. Second is the ERDL - Tulane symposium procedures edited by Bach[4]. Although the symposium is no longer recent (1957), it nevertheless is a major landmark and an excellent reference. The study by

Obitz and McCord of Falcon Research and Development Company is classified Confidential. A brief review of it has been issued as an addendum (Addendum Report No. BAT-171-6-1, dated January 15, 1965) to this report and is entitled "Summary of 'The Development of Weapons for Psychological Warfare' - A Study Conducted by the Falcon Research and Development Co." (U). The ERDL-Tulane Symposium is discussed below.

The proceedings of this 1957 symposium on flicker contain the experimental results of many pertinent studies. A summary of the Tulane studies on the effects of flickering light on human subjects performed by Bach, Sperry, Jr., and Ray follows:

"Unpleasant or hypnotic subjective effects are consistently reported when subjects are exposed to diffuse flickering light". The most effective frequency for eliciting these responses is 9 per second, although any particular value of frequency is not extremely critical between the limits of 7 and 20 flashes per second. The effects are not cumulative with time of exposure beyond 5 minutes. Light:dark ratios smaller than 1:3 seem more effective than larger ratios. Maximum effects occur with high brightness in the field of view. (Brightness values above the threshold of pain introduce complications in the assessment of the results.) Monochromatic light seems to hold no advantages over white light as indicated by preliminary tests with red, blue, and white light. Some degree of drowsiness was reported in all cases where the light was modulated by the spontaneous 9-cycle-per-second EEG activity of the subject.

There was also a series of three field experiments reported at this symposium. These are reviewed in detail in a later section titled "Methods for Using Pulsed Light in Combat."

The chief consistent finding was the production of sensations indicating some degree of loss of consciousness. These were often so slight as to be inconsequential in any other context. Consistent production of dizziness, sleep, drowsiness, hypnotism, etc., was highly characteristic. Actual sleep was not produced, as borne out by the failure of objective tests to provide any evidence of loss of cognition, but it is apparent that when a sensation of an effect is reported by a subject, that subject is close to actually experiencing the effect itself (i.e., a subject who feels sleepy is on the verge of being asleep). Some state approaching sleep, but not actually sleep can be achieved by using flickering light on human subjects.

For all locomotive and even for many hand-eye coordination tasks, it appears that training or simple experience could enable the average subject to compensate for any of the stroboscopic effects.

Brazier[8] makes some very interesting points in her study of flicker in these same proceedings. In normal groups studied over an 11-year period, a normal subject who gave a paroxysmal response was never found; they never had a response like this from a subject who was not a patient, a prospective patient, or just on the threshold. As to the effect of flicker, they found great individual variation in the degree to which the basic rhythms can be disturbed by the imposed periodicity of the flash. The question is whether there is any relation between the sensations which are epxerienced and the degree to which the basic rhythms are disturbed. With an aperiodic stimulus whose aperiodicity is not detected by the subjects, there are far more spontaneous responses showing disturbance than when the triggering stimulus is a fundamental of the natural frequency. Brazier suggests that aperiodic stimulus can perhaps be more disturbing to the brain than one which can alter the brain's own rhythms.

Although she has not done a systematic study, Brazier found disturbing effects by using a rhythmic flash with an analyzer, and flashing with a periodic rhythm until a response to the flash was elicited; then changing the frequency (by half of a cycle or 1 cycle perhaps), and then, after letting the subject's brain become adjusted to that, changing it again. These small changes of half of a cycle were not detected by the subject, but seemed to be very disturbing to him. Brazier found, and thinks that the Tulane group found, too, that some subjects who were flashed very close to their own alpha rhythms were lulled by it. "In fact, it is a rather pleasant and somnolent sort of effect, so I think that very big differences can be brought out by allowing the brain to get set, jerking it out again, giving it a new rhythm, and then jerking it out again."

In the wrap-up of these proceedings the following remarks were made: "Enemy troops who are forced to resort to protective countermeasures are just as effectively distracted as if they had lost consciousness or had become dizzy. The psychological maneuver may therefore be more effective than some physiological reaction." In the section on battlefield stress, it was indicated that:

(1) "Flicker would be useful in future battlefield situations where nuclear weapons are involved.

(2) "Even a few seconds of distraction provides an advantage. Adversive movements by susceptible enemy troops in order to avoid flicker would provide an advantage to friendly troops. Present sources of flicker or flash in the battlefield probably cause discomfort through excessive pupillo motor activity from the slow rates and high intensities one ordinarily experiences.

(3) "Panic and fear, bred by rumor, are important elements in the effectiveness of flicker.

(4) "Fear and the apprehension of death in the actual combat situation provide a stress factor which cannot easily be duplicated in the laboratory or on the training field.

(5) "Flicker may be the one additional stress required to cause annoying sensations, confused consciousness, sleep or unconsciousness when combined with other stresses such as hunger, sleeplessness, critical tasks, extremes of temperature, in the battlefield situation."

The conclusions of this symposium's proceedings indicate that "those flicker effects which interfere with consciousness appear at frequencies related to the alpha rhythm of the EEG, or at 10 cycles per second. Annoying or irritating sensations seem to occur with aperiodic flashing or rhythmic flashes at 3 to 5 cycles per second. Visual illusions appear to be produced by frequencies above 10 to 12 cycles per second. Flickering of other sensory modalities may influence the ease of induction of the desired effects of the visual flicker. Auditory flicker is particularly promising in this regard. Stress, comparable to that produced in actual combat, may be needed to completely elucidate the practical effects of flicker as far as military applications are concerned. It appears likely that high intensities of light will be more effective in producing the desired effects of flicker although much remains to be done to determine the optimum light and dark intervals, background contrasts, and effects of stray light."

Individual Studies

The following presents the highlights of a number of documents that seemed sufficiently significant to warrant individual review in this survey. To provide some degree of organization, these reviews are grouped under the headings stimulus variables, subject variables, and response variables. Naturally, none of the studies deals with only one class of variables, but each study has been categorized under the heading which seems best to reflect the study's major significance.

Stimulus Variables

Several studies have been informative particularly with regard to the stimulus parameters.

Self-Administered Stimuli. A review of this topic(30) quotes Gastaut's report on epileptics examined in his department. "Fifteen per cent only produced spikes and waves during intermittent photic stimulation; only 3 per cent display a clinical light sensitivity such as difficulty with sun or other strong light and the need to wear dark glasses. Four in 1,000 only have shown either grand mal or petit mal seizures triggered by accidental flickering light, for instance, such as may be caused by traveling in a vehicle among an avenue of trees, or by sun reflections by waves or snow. Only one patient in 1,000 has induced absences in herself with intent."

Thus, even in an epileptic population, only 15 per cent showed epileptiform waves as a result of photic stimulation. The critical stimulation frequency of these epileptic patients varied greatly from much below the typical alpha range to well above it. (In one case the response range was from 4 to 32 flashes per second.) Convulsions can be induced by hand wave, eye closing, moving the venetian blind, staring at the sun while riding on a bus in a poplar-lined avenue (assumed to be about 6 to 7 flashes per second), TV flickering, and blinking in bright light. Many of the patients showed questionable effects in reacting to flicker. In certain cases a single flash was able to trigger general discharge.

Laboratory Stimuli. The usual stimuli used are produced by xenon or similar flash tubes. These are of short duration (in the range from

10 to 50 microseconds) and high intensity (10^4 or higher foot-candles), and therefore the light:dark ratio is quite small. In the studies using light:dark ratios on the order of 1:1, generally the intensity levels were much lower, i.e., the work of Stern[31] and Ulett and Johnson[33]. The effects noted in the last-mentioned work do not differ greatly from those obtained in the studies using short light flashes. The background lighting during most of the studies has the subject in either a completely darkened or dimly lit room. The subject is usually sitting or lying, in a comfortable position, in a normal range of temperature (not usually stated but probably above 70 degrees).

Kroger and Schneider[22] discuss the brain-wave synchronizer, "an instrument specifically designed to induce various levels of hypnosis by subliminal and photic stimulation of the brain waves". These authors see this device as a useful aid for hypnotic induction. It was noted by one of the authors, Schneider, that on several occasions during World War II, radar operators readily entered into a relaxed state and others fell into deep hypnotic states while watching signals on the radar screen.

In general, the photic stimulation used is such that the entire retinal field is illuminated by the flash. Reference 30 notes that it is not necessary to have complete retinal illumination to produce an epileptic seizure, but that the movement of the image across the retina may also be effective (such as the case of moving the head up and down while viewing the sun through venetian blinds).

Marshall, et al.[24], also indicate that red light is the most effective, and that some degree of protection might be afforded by using blue or green goggles. However, Erwin, et al.[13], point out that the relative effectiveness of different colors can not be evaluated properly unless the different wavelengths are equated on intensity.

Duration of exposure is a questionable factor. Alexander and Chiles[3] report on four subjects who were exposed up to 2-1/2 hours with no ill effects. This is in contradiction to the results of the previously cited study.

Subject Variables

Apart from the well-established susceptibility of epileptics to photogenic seizure, there are other characteristics of subjects which apparently affect their susceptibility. Some of these are discussed below.

Effects of Attention and Concentration. Johnson, Davidoff, and Mann[18] conducted an experiment using epileptic patients. EEG's were recorded while photic stimulation was applied with a Grass PS-2 Photic Stimulator. The total examination period was from 45 to 90 minutes per patient. The subjects had three tasks: simple tapping, repeating digits, and serial subtraction. Attempts were made to sample functioning during both normal and abnormal EEG activity, but the latter was difficult and "impossible in some patients for the directed attention and concentration necessary to perform the task often interrupted the abnormal discharge and in some patients probably prevented paroxysmal discharges."

During sub-clinical discharges in 12 patients, two showed performance interruption. During clinical discharges (7 patients), all showed some impairment during one or more tasks. It must be emphasized that these data were obtained on 24 epileptic patients and not normals. From this work, it could be assumed that the performance of a normal population would have been unaffected.

Johnson[16] discussed the problem of flicker vertigo, which has the following symptoms: uneasiness, nervousness, dizziness, and in some instances a feeling of severe panic. Johnson used a sample of 102 pilots in this study. Performance was not affected by photic stimulation when the subject's attention was deliberately focused on the task.

Age. The EEG literature contains large numbers of references to the "immature" EEG patterns to be found in young persons. According to the most general view of childrens' EEG patterns, brain immaturity is considered to result in biological liability of the EEG and interpretations of childrens' EEG patterns must be founded upon special consideration of such immaturity.

Brandt, Brandt, and Bollmond[7] discussed the matter of photic driving and their findings with children below 15 years of age. These authors subjected 120 normal children to 6-minute periods of photic stimulation at various flicker frequencies. Paroxysmal EEG response to photic stimulation was observed in about 26 per cent of the school-age children, although fewer than 6 per cent presented deviations from normality in EEG before visual stimulation had been performed. The authors concluded that response to visual stimulation is largely dependent upon "undefined" constitutional factors.

This paper has a special pertinence to the question as to whether subjects from other races or cultures, some of whom have been occasionally reported to show immature EEG's even among adult subjects, would reveal a greater acceptability to photic-flicker stimulants.

Cultural Variables. Anand, Chhina and Singh(6) explored the modification of EEG in Asian cultures, specifically in Yogis. Since the study summarized in this report relates to possible behavioral and EEG changes in foreign cultures, these findings may be relevant. The authors have found that during Samadhi, a type of mediative trance, the Yogis will experience a larger amplitude, same frequency, alpha rhythm, as before the trance was induced. They have further found that this alpha remains unchanged during the following types of stimulation: bright light, loud clapping, vibration, and being touched with a hot glass tube. All of these stimuli before meditation produced alpha blocking.

Repeated Exposure. Yoshii and Hockaday(35) described the results of frequently repeated photic driving upon cats. In a study of the effects of conditioning the photic-driving response to pure tone, these authors exposed 11 chronically prepared unanesthetized cats to a 7.5-per-second flicker rate for a duration of 12 seconds, more than 50 times per day. They reported that repeated flicker stimulation of this sort for more than one week in some cases caused the appearance of generalized evoked potentials of increased amplitude in the frontal cortex amygdala, caudate nucleus, and internal capsule. Frequency characteristic waves were observed not only during driving periods and in response to a conditioned tone stimulus, but also in the background intervals. The frequency characteristic waves at first appeared at random in cortical and sub-cortical structures, but after a week of continued treatment they were restricted to the cortex. The form of activity which exhibited cortically was described as bursts of spike discharge. There was also noted the appearance of spike and wave discharges. This paper, though it is primarily concerned with conditioning the response to photic driving, contains the implication that often-repeated photic driving stimulus administered in relatively brief bursts may induce epileptiform discharges in mammals. No behavioral changes were noted in the cats used in this experiment.

Response Variables

The review of the general literature indicates that epileptiform manifestations as a consequence of photic stimulation are relatively rare, even though it is frequently possible to demonstrate paroxysmal EEG activity in a substantial percentage of subjects as a result of photic stimulation sustained over some period of time. The question then arises as to whether there are any other physiological changes induced by photic stimulation that might have a bearing upon the ability of a subject to perform in normal fashion.

A study by Mundy-Castle[27] is illustrative of the infrequent occurrence of seizures. He studied two groups, one consisting of 154 young normal adults, mean age 22 years and standard deviation 5 years, and the other of 40 mentally normal seniles, mean age 75 years, standard deviation 9 years. A Scophony electronic stroboscope emitted a blue-white light flash of approximately 88,000 candles. Duration of the flash was 15 micro-seconds, with the lamp 15 centimeters from the subjects' eyes "so that the whole of both visual fields was stimulated". Subjects rested on a couch in a moderately lit room, both with eyes open and with eyes closed. Frequency varied from 3.5 flashes per second to about 25 per second, and went as high as 100 flashes per second, then decreased rapidly back down to 15 per second. This procedure was repeated several times. The EEG results are fairly extensive and are not discussed here. Qualitative results included abnormal responses. In the two groups totalling 194 subjects, 7 displayed typical poly-spike or wave-spike characteristics. Six (i.e., less than 3 per cent) of these 7 experienced either violent-to-mild jerks or slight twitches. But consciousness seemed rarely to be affected. No other behavioral manifestations were noted.

In Johnson's previously referenced study(16), 16 out of the 102 pilots studied reported subjective sensations which included tension, apprehensiveness, inability to think, disorientation, a hypnotic effect, or being bothered. No feeling of nausea or dizziness was reported. Nine of these pilots who reported discomfort had been bothered by flicker during flight. Twenty-two subjects, as indicated by their EEG, "became drowsy or went into light sleep during flicker". The author concludes then that for 21.5 per cent of his sample "the degree of alertness changed markedly in flicker". Further remarks on his results: "As indicated above, after the resting flicker survey, each pilot was given a series of tasks and then re-flickered, with a comparable set of tasks being given during flicker. There was no significant difference between performance with and without flicker on repeating digits, addition, or serial subtraction, and no change in tapping rate could be associated with either an increase or decrease in flicker frequency."

As to the 22 pilots who became drowsy under photic pulsing, boredom did not seem to be an adequate explanation. Not only were they alert before flicker, but many of them were unaware that they were going to sleep. Those who did realize what was happening indicated that they could not prevent it. "I felt myself getting sleepy but couldn't stay awake" was a remark made by nine of the pilots. Two described the flicker effect as "hypnotic".

Johnson concluded: "<u>It would thus seem that any discussion of flicker reaction in helicopter pilots should stress not only the problems of vertigo, distraction, nausea, and the possible alterations of consciousness, but also the possible hypnotic or somniferous potentialities</u>".

None of the 102 helicopter pilots showed any paroxysmal EEG response during photic flicker. "That these pilots are different from the samples generally studied is obvious. All of these pilots have survived a rigid pre-flight medical examination plus yearly medical examinations. These pilots are those that have been left after the various medical casualities, those lost in flight training and those who gave up flying soon after graduation have been deleted."

Confirmation comes from a study by Aitken, Ferres, and Gedye[2]. They were testing the distraction factor caused by anti-collision lights used on aircraft. Photic stimulation was applied at fixed frequencies between 1 and 2.33 cycles per second to a total of 10 normal subjects (5 of which were pilots in practice), aged 25 to 37 years. Low-illumination flashes appeared on a screen in front of the subjects, who were then asked to state their preference, i.e., "if you were flying, which of these frequencies would be most desirable". 1.33 cycles per second was chosen most often.

Lesser preferences at lower and higher frequencies were found. This agrees with the subjective reports of drowsiness at the low frequencies and of mild irritation at the high frequencies.

A paper by Johnson and Davidoff(17) describes changes in autonomic activity occurring during paroxysmal EEG activity, both spontaneous and photically induced. The subjects in this study were 6 epileptic patients and 5 non-epileptic subjects. In the non-epileptic subjects and in the epileptics as well, autonomic changes in skin resistance (GSR), heart rate, skin temperature, respiration, and finger vasomotor activity were observed when the paroxysmal EEG discharges were of the "clinical" type. No autonomic changes of consequence were observed in those normal subjects in whom it was not possible to induce epileptiform EEG changes by photic drive. The conclusion relevant to the present study, that might be drawn from the quoted study(17) is that it is unlikely that photic driving would induce symptoms other than epileptiform manifestations in the normal subjects.

A report by Ulett(32), significantly titled "Flicker Sickness", indicates that 87 out of 306 control subjects (over 28 per cent) showed some reaction to pulsed light. A 1,000-watt tungsten-filament movie projector lamp was pulsed at frequencies from 2 to 30 per second on an opal glass screen, filling the subject's visual field with light of 100 to 200-foot-candle intensity. Reactions were "...visceral (nausea, headache, etc.) or kinesthetic (body moving in space) sensations in varying degrees. Sixteen of the 87 (over 5 per cent of the total 306 control subjects)"...had disturbances of consciousness, including fainting, syncope, and convulsive phenomena".

METHODS FOR USING PULSED LIGHT IN COMBAT

This section of the report discusses possible methods for applying pulsed-light techniques in combat. There appear to be four distinct steps in research aimed at the possible combat use of pulsed light: (1) laboratory research, (2) field testing, (3) research in countermeasures, and (4) combat evaluation of the most promising techniques. In the progressions from laboratory studies through field tests to combat evaluation, the investigator's control over test conditions and over test subjects decreases dramatically. The corresponding changes in requirements for techniques and equipment may be equally great.

Laboratory Techniques

As has been pointed out previously, a considerable amount of research on flickering light has been done in the laboratory. Typically, the laboratory investigation involves the following conditions: The subject is seated in a comfortable chair in a softly lit or darkened room. He is then presented a high-intensity, diffused light flickering at approximately 10 cycles per second. Frequently, the subject is asked to close his eyes, thus providing effectively a red filter over the eyes.

Field Experiments

The state-of-the-art search turned up only one investigation of the effects of flickering light on a group of subjects under field conditions. It is being conducted by the University of Oklahoma at the Psychological Weapons Research Facility, Advanced Technical BR/ATWR Weapons Division at Eglin Air Force Base. Since this research program is classified, it will not be reviewed here; however, it is closely related to a series of investigations conducted at Tulane University and the U. S. Army Engineering Research and Development Laboratories in the 1950's, which are reviewed below.

These studies examined the effect on rifle-shooting accuracy of a single 6-cycle-per-second flickering light under conditions of (1) no ambient illumination, (2) low ambient illumination with the source behind the attacking troops, and (3) low ambient illumination with the source behind the target being attacked.

In the first study an ambient period was employed as a standard of comparison. This ambient period was equated in brightness to the subjective average brightness of the target during the flash period. The average flicker brightness was 0.01 foot-lambert at 6 cycles per second. The results of this study are presented in Table 1. Table 1 shows that a significantly greater score was obtained under the ambient condition than under the flickering condition.

As the Tulane experimenters noted, the first experiment was unrealistic in at least two ways. First, the levels of brightness were much higher than would be encountered in combat, and second, the condition of no ambient light during the flash period was artificial. Therefore, a second experiment was designed. This experiment was identical to the first except that a 0.001 foot-lambert ambient brightness was introduced and the flashing light was superimposed upon this low-level ambient brightness. The results of the second experiment are shown in Table 2. The analysis shows that there was no significant difference between the flickering and ambient conditions.

The third experiment was similar to the second, but with one major exception, namely, that the flashing light source was placed behind the target. This is equivalent to the view which attacking forces would have of the friendly forces. The results of this third experiment are shown in Table 3. The analysis barely reached the 0.1 level of confidence; however, the experimenters believed that had the number of observations been increased, this difference would have been statistically more significant.

If an attempt were to be made to apply laboratory techniques to field experimentation, the following procedure is suggested. A very-high-intensity searchlight (approximately 8,000,000 candle power) could be flashed at 8 to 14 cycles per second through red smoke. The red smoke would serve both to diffuse the light and change the color to red. Ideally, the subjects should be fatigued and stressed in some manner to simulate combat conditions. It is suggested that some behavioral dependent variable be observed rather than simply EEG's since the correlation of EEG patterns and behavior is still somewhat uncertain.

Countermeasures

Very little research has been done on possible countermeasures to flickering light; however, three possibilities appear to exist.

TABLE 1. EXPERIMENT EMPLOYING AMBIENT VERSUS FLASHING LIGHT SOURCE (SOURCE IN FRONT OF TARGET)

Condition	Mean (Target Scores)	Mean Difference	S_{D_M}	t	p
Flicker	18.6				
		19.0	7.3	2.6	0.5
Ambient	37.6				

TABLE 2. AMBIENT VERSUS AMBIENT WITH SUPERIMPOSED FLASH (SOURCES MOUNTED IN FRONT OF TARGET)

Condition	Mean (No. of hits)	Mean Difference	S_{D_M}	t	p
Flicker	2.88				
		0.75	0.50	1.50	0.05
Ambient	2.13				

TABLE 3. AMBIENT VERSUS AMBIENT WITH SUPERIMPOSED FLASH (SOURCE MOUNTED BEHIND TARGET)

Condition	Mean (No. of hits)	Mean Difference	S_{D_M}	t	p
Flicker	2.20				
		2.30	1.24	1.85	0.10
Ambient	4.50				

First, it may be possible to reduce the disabling effect of flickering light by the wearing of colored glasses. It has been found that many photo-convulsive epileptics can reduce and sometimes eliminate completely seizures caused by photic stimulation. A second, and rather elementary, counter-measure would be simply to shoot out the light source. This would probably be a relatively easy task with the use of tracer bullets; however, it might be quite difficult without the use of tracers. Third, it may be possible to gradually condition subjects so as to reduce the disabling effects of light flicker. The probability of success with this technique is probably rather small; however, it may be worth investigating.

A fourth, and inadequate countermeasure also exists. This is simply shielding the eyes against the flash. This technique could very easily provide the few seconds of partial incapacitation that could lead to a combat advantage.

Combat Experience

There appear to be very few relevant data from actual combat experiences. Captain C. H. Orr in the Tulane Symposium, however, does cite some anecdotal incidents of disabling effects from flickering light. Captain Orr also discusses the possible importance of fear and its influence on the behavioral effects of flickering lights. He points out that flicker may be considerably more effective in disabling combat troops than in disabling non-stressed field-experiment subjects. This same possibility exists in comparing laboratory results with those in combat. Captain Orr notes that even a few seconds of partial incapacitation may be sufficient to produce a combat advantage.

RESEARCH TRENDS*

Researchers are in general agreement that photic stimulation has the potential of causing disabling behavioral effects on a select group of individuals[f,k].

It seems somewhat premature to look for any one stimulus to be capable of inducing incapacitating effects[e,j,l]. Current clinical or laboratory evidence is still too meager to warrant any valid conclusions. Current researchers are concerning themselves, and perhaps rightly so, in determining an agreeable definition of the term "incapacitation"[a-c,g,i,j].

Researchers investigating psychological weaponry agree that photic or auditory drive alone is insufficient to produce more than rare cases of actual disability[g,i,k]. Interestingly enough, however, the same investigators point out the occurrence of numerous cases of partial disability. A number of recent reports cite subjects who have experienced nausea, dizziness, drowsiness, visual phenomena, monotony, boredom, fatigue, etc.[a,b,e,f,j-m].

Based upon these preliminary findings, projected research might be directed toward the development of lesser effects of disability. One must consider that maybe it is not completely necessary to incapacitate an individual in order to render him ineffectual as a military combatant[a,b,g,j,k,m].

To state that past research has resulted in a "no significant effect" conclusion would, of course, be a gross untruth. Consistent improvement

*Letters in parentheses, used to designate references in this section, refer to personal communications from persons listed in Appendix B.

in laboratory techniques has resulted in increased basic EEG work, particularly with regard to "drive activation". A review of the recent literature indicates that while much of the basic research has been accomplished, more laboratory testing is needed.

It is in this light then that new research trends are developing. The following topological areas summarize the current research trends; these trends are based on a comparison of listings in the 1963 and 1964 Psychological Abstracts and personal communication with persons considered to be authoritative experts in the subject matter area (references listed in Appendix B):

Psychopharmacology - Heavy in recent investigation

Suggestion and hypnosis - Heavy in recent investigation

Audiogenic seizure - Light but steady in recent investigation

Sleep - Particularly deprivation

Stress - As an activator in major convulsions

EEG in conjunction with multi-stimuli.

Perhaps the area of strongest concentration with regard to current research is the area of sleep. Stress also is under current investigation, primarily in conjunction with additional stimuli(1). Quite recently, a strong trend appears to be developing on the effects of suggestion, particularly with regard to sleep and stress situations(1). Basic research is continuing in the area of laser beams. However, the accumulated literature indicates primarily biological considerations*; some work has been done on developing a laser rifle.

*Armed Forces Institute of Pathology, Annual Research Progress Report, Army Research and Development Command, "Biological Investigation of Effects of the Laser Beam", Task Number 6, pp 4-15.

It seems feasible to evaluate the behavioral aspect of multi-stimuli in conjunction with photic and auditory drive. These data can and should be obtained in the laboratory. Such data should be evaluated both for groups and for individual subjects.

New areas under present consideration indicate that extensive evaluation in the laboratory must take place before one could look hopefully toward any form of field evaluation.

In summary, recent investigation indicates that present photic stimulants alone are relatively ineffective, except as noted in rare cases, in producing incapacitating effects. The current research trends indicate that photic driving in conjunction with multi-stimulus, i.e., psychopharmacological agents, monotony, fatigue, hallucinations, stress, sleep, suggestion, etc., offers promising results in the laboratory in terms of producing partial disability.

CONCLUSIONS

On the basis of this brief state-of-the-art review, conclusions are drawn in three categories below.

Information Needed

Although there is an extensive literature on pulsed-light effects, very little of it has been concerned with incapacitation. The available evidence suggests that "distraction" may be a better word for the effects found than "incapacitation". It is considered that information related to the following is needed to fill the gaps:

(1) Development of acceptable test situations and scoring procedures for use in measuring the performance decrement.

(2) Testing of a number of healthy, military-aged males under the most promising stimulus conditions, using the standard test situation.

Feasibility

The information uncovered indicates that seizures could be induced in less than 1 per cent of the population at best, and other more moderately disabling effects (e.g., fainting) may bring the percentage up to 5 or 6. Field equipment for administering the photic stimuli has not been developed, and may represent engineering design problems of some magnitude. Countermeasures by the enemy may be simple and effective, e.g., looking away, wearing goggles, shooting out the lights, etc. It should be noted that in some cultures, the occurrence of seizures in a few of the troops may cause the others to believe that the gods are favorable to their cause.

Future Research

In view of the slight element of feasibility related to the application of pulsed-light effects, possibly some authorities will think the potential is great enough to warrant more research. Of course, from the research standpoint, the answers are not complete, and if it is considered worth while to work on the basis of 5 per cent effectiveness, there may be some point in undertaking additional studies. If so, it is recommended that such studies be focussed on practical problems; specifically, any future research should be aimed at the following:

(1) Practical review of the engineering feasibility of delivering photic stimulation under combat conditions.

(2) Investigation of performance decrement under photic distraction, with these conditions:

(a) performance tasks of military type

(b) quantitative, militarily meaningful performance measures

(c) evaluation under simulated-combat conditions.

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APPENDIX A

PUBLICATIONS SCREENED

Biological Abstracts
January, 1929, to October 15, 1964

Chemical Abstracts
January, 1950, to October 15, 1964

Index Medicus
January, 1960, to October 15, 1964

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January, 1954, to October, 1964

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APPENDIX B

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The report summarizes the state of the art and feasibility of using pulsed light to affect combat performance by inducing photogenic and epileptiform seizures.

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